# APPENDIX I -- SIMULATION OF CONSUMPTIVE USES WITHIN THE LOXAHATCHEE BASIN

## CONTENTS



## Introduction

Consumptive uses of water sources include those from public water supply, irrigation and self-supplied residential wells. The overall effect of consumptive uses on flows to the Northwest Fork of the Loxahatchee River was considered as part of the MFL process. Use of the Surficial Aquifer and the Loxahatchee River to meet local demands is a resource function. Several approaches were used to estimate the magnitude and proportion that consumptive uses may comprise of the watershed's hydrologic budget.

To address this issue, District staff analyzed available hydrogeologic data and conducted a number of groundwater model simulations. Data were obtained from SFWMD and USGS databases. Model scenarios were simulated with a modified USGS, three-dimensional, finite difference, groundwater flow model code (MODFLOW-96) that was developed by the SFWMD for northern Palm Beach County (SFWMD 2002). This model is known as the Northern Palm Beach Groundwater Model, or NPB Model. This model provided a means to estimate the relative effects of consumptive uses within the basin on water levels in Loxahatchee Slough and deliveries to the Northwest Fork of Loxahatchee River during selected wet, normal and dry periods.

MODFLOW is primarily a computer software code for evaluating groundwater flow conditions. The code utilized in this report does not incorporate a surface/groundwater module. Therefore, overland flow and associated surface water routing through canal networks is not directly simulated and the effects of consumptive use withdrawals on overland and riverine flows should only be considered as gross estimates.

## Model Description

The NPB MODFLOW Model includes that portion of northern Palm Beach County that is bounded to the west by the canals, L-10 and L-12 and to the east by the Atlantic Ocean. The southern and northern boundaries include the C-51 canal and the Palm Beach-Martin County line, respectively. Boundaries and major features in the model domain are shown in **Figure I-1.**

The MODFLOW Computer code is used by the District as a tool to assist in decision making for various purposes, including water supply planning, facility design evaluations, rule-making, and consumptive use permitting. The modified, SFWMD version, of MODFLOW-96 includes three new modules: the Wetland and Diversion Packages, the Operations Package and a Multiple Well Package, each of which are briefly described below.

- <u>Wetland and Diversion Package:</u> This module within MODFLOW enables the top layer of the model's grid system to include overland flow through dense vegetation (including surface storage) and channel flow through slough networks, thus more accurately simulating wetland hydroperiods and canal stages encountered within South Florida.
- <u>Operations Package:</u> This module allows water to be moved within the MODFLOW model to simulate the operational transfer of water (e.g. opening a structure or a pump) from one location to another. The Operations Package is capable of managing flows into and out of reservoirs, such as Storm Water Treatment Areas and Aquifer Storage and Recovery wells, and can be used to provide boundary information (e.g. available runoff for potential capture by a reservoir).
- <u>Well Package:</u> This module allows the user to keep different well data sets (e.g., public water supply wells, agricultural wells etc.) independent of each other, thereby evaluating the effects of each type of water use separately.

## Model Limitations

MODFLOW is primarily a computer software code for evaluating groundwater flow conditions. The code utilized in this report does not incorporate a surface/groundwater module. Therefore, overland flow and associated surface water routing through canal networks is not directly simulated and the effects of consumptive use withdrawals on overland flows should only be considered as gross estimates. It is recommended that future model updates incorporate a surface water routing module to provide a greater understanding of the canal systems within northern Palm Beach County.

The NPB Model was utilized for this investigation because it was readily available and covered the area of concern. In addition, it was assumed that groundwater consumptive use in the vicinity of the Loxahatchee Slough and River was of concern and a model, which addressed groundwater systems, was required.

## Model Coverage and Components

The model domain for the NPB Model is uniformly organized into 0.25 mile by 0.25 mile grid cells, each covering 0.0625 sq. miles or 40 acres, resulting in a full grid of 9,280 cells per

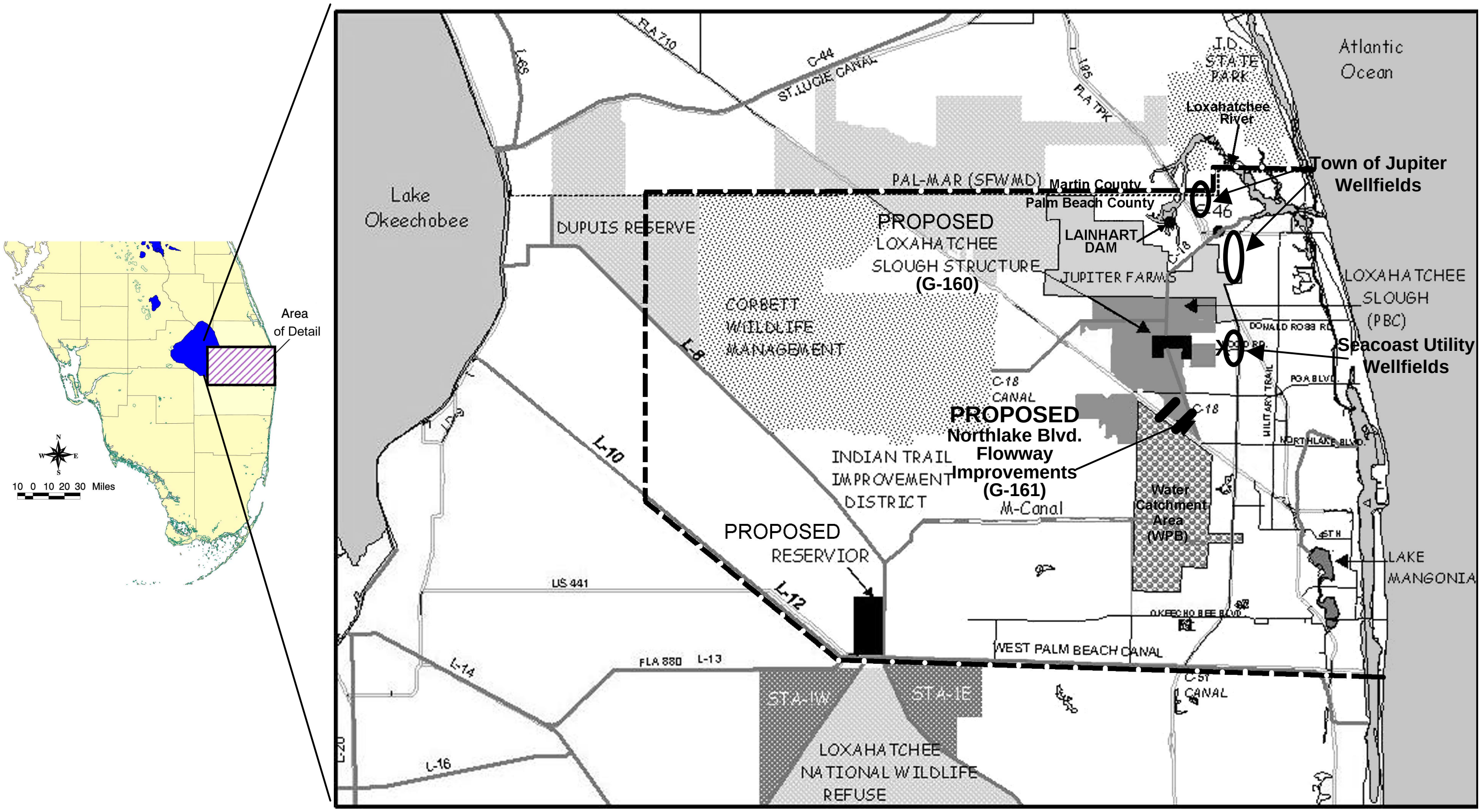


**Figure I-1**. Location and major features of northern Palm Beach groundwater model study area (proposed G-160 and G-161 structures were not included in the modeling scenario).

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layer with 80 rows and 116 columns. This horizontal grid allows for a degree of regional accuracy with manageable run-times and post-processing times. The grid limits (corner nodes) in U.S. State Plane Florida East NAD 27 coordinates are listed below:

$x_{min}$ = 658,906 Easting;

$x_{max}$ = 812,026 Easting;

$y_{min}$ = 851,308 Northing ;

$y_{max}$ = 956,908 Northing.

The majority of the Loxahatchee Watershed is underlain by the Surficial Aquifer System (SAS). Portions of the Biscayne Aquifer exist in this area, as well. The model divides the SAS (including the Biscayne Aquifer portions, if present) into seven layers. The model provides a representation of the hydrogeologic zones within the aquifer, as well as the partial penetration of canals and wells. The layering scheme incorporates the two principal permeable zones targeted by production wells (i.e., a highly transmissive zone representing the prolific Biscayne Aquifer and a more laterally extensive, moderately transmissive, production zone). **Figure I-2** shows the conceptual cross section of hydrogeologic zones within the SAS.

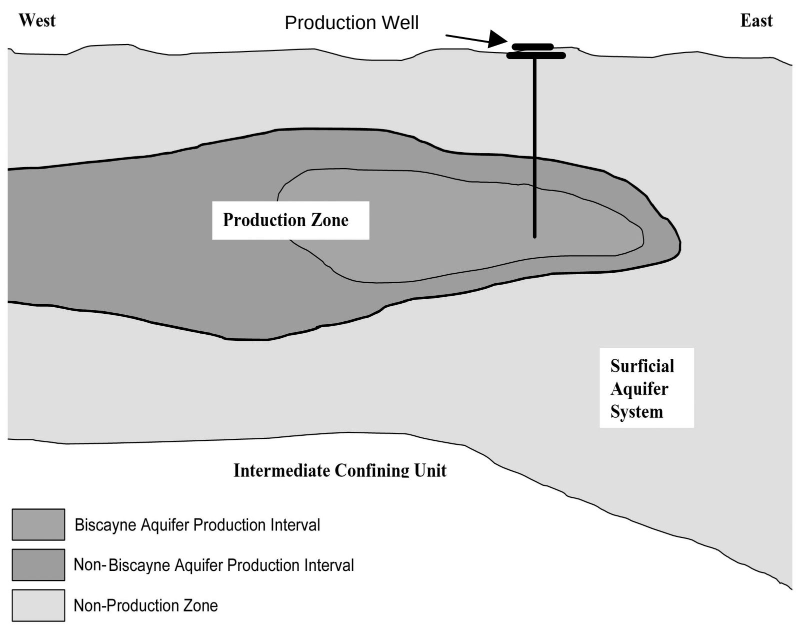


Figure I-2. Representative aquifer cross-section in Palm Beach County.

## Model Calibration

Calibration of a model is achieved when the model is capable of simulating a set of field measurements within specified tolerances. The model was calibrated to transient conditions that included groundwater stages, or head, from wells within the study area, and flows at the Lainhart Dam. For calibration of heads, the total number of observation wells used in the calibration was 19 - one observation well located in Layer 3, five wells in Layer 4 and 13 wells in Layer 2. For calibration of surface water flows, data for Lainhart Dam were extracted from the SFWMD's DBHydro database and modified based upon the weir equation. Calibration targets included those average daily flows from Lainhart Dam that were less than 50 cfs. MODFLOW is a groundwater model that does not have the capability of simulating storm driven events. In addition, the primary purpose of this analysis was to document effects that occur under low flow conditions. Therefore, flows from Lainhart Dam that exceeded 50 cfs were excluded from the calibration targets. This limitation results in a reduction of the reliability of the estimates produced for average and wet periods.

The model calibration period extended from January 1987 through December 1995. This eight-year period of record incorporated "normal," "wet," and "drought" conditions, which allowed assessment of water management scenarios under conditions ranging from excess rainfall conditions (1994-95) to extreme drought conditions (1988-89). A daily time step was used, due to the large daily variations in time series data such as canal stages, rainfall, evapotranspiration, and pumpage.

The "trial and error" method was used to calibrate the NPB Model. To apply this method, parameter values are adjusted manually in sequential model runs. The results of calibration were evaluated both qualitatively and quantitatively. Results of the calibration of the model indicated that in all cases, average absolute errors were less than 1.0 foot for head calibration, and the trend match between hydrographs showing simulated versus historical groundwater levels was judged to be satisfactory for modeling purposes (SFWMD 2002). For calibration of flow, the absolute errors were less than 10 cfs during 55 percent of the simulation period. The average mean of the field data for Lainhart Dam was 24.1 cfs and the average mean of the model results for the Lainhart Dam was 24.7 cfs, for calibration targets of flow from Lainhart Dam less than 50 cfs. For flows from Lainhart Dam less than 65 cfs, the average for the field data was 30.8 cfs and the average for modeled data was 25.4 cfs. The results of the surface water calibration clearly indicate that under dry conditions, when the C-18 canal is receiving primarily inflow from the groundwater system, MODFLOW can provide a reasonable estimate. However, once significant rainfall events occur, the model cannot adequately address these surface water flows. It is recommended that, in the future, a surface water flow component should be added to the NPB Model to help achieve better calibration of surface water flow. In addition, the model boundaries should be expanded northward to include the entire estuary basin where surface and groundwater flows are contributing.

## Model Application

The Northern Palm Beach County (MODFLOW) model was applied to three different scenarios to simulate the effects of consumptive uses within the Loxahatchee watershed. Specific emphasis was placed on hydrologic conditions in the C-18 Canal Basin, which provides water for a variety of consumptive uses, including public water supply, irrigation and self-supplied residential use. The three model scenarios presented below differ with respect to the way groundwater withdrawals and proposed surface water systems are represented in the model. These simulations are summarized as follows:

- “1988-1995 Actual Pumpage” model run: This scenario represents hydrologic conditions in the basin prior to recent land use and consumptive use permitting changes that have occurred in the watershed since 1995. Data for the Well Package were extracted from individual water use permits issued by the South Florida Water Management District’s Regulation Department for irrigation users. For the PWS systems, actual data for each month and year of the simulation period were used. That is, what they actually reported using in March, 1992 is actually simulated. An important point in evaluating this model run, since it does include actual PWS pumpage data, was that in 1988-1990, this area of the District was under a Phase 1 and Phase 2 water restriction which required mandatory water reductions that were simulated in the model
- “No Pumping” model run: This model scenario was the same as the “1988-1995 Actual Pumpage” model run, except no groundwater withdrawals were simulated within the basin (i.e., “pumps off” scenario).
- “Permitted” model run: This scenario best represents present (2001) hydrologic conditions within the watershed. Data for the Well Package were extracted from individual water use permits issued by the South Florida Water Management District. It is important to note that the withdrawals used in the model were permitted amounts rather than actual pumpages. Therefore, in this run, model results are considered conservative (i.e. they may over-estimate adverse impacts) with respect to quantifying the effects of consumptive uses as compared to conditions today. In addition, variations in withdrawal rates due to seasonal changes were not taken into account in this model run. The 1989-1990 water restrictions were not simulated in this model run.

## Model Results

The data from the model were adjusted, based on field data, to represent an average rainfall year (1991-1992) and drought conditions (1988-1989), for the Historical and Permitted model run scenarios. Historical flow data obtained from USGS and SFWMD records for the Lainhart Dam, Hobe Grove Ditch, Kitching Creek and Cypress Creek were averaged for a nearly-average rainfall year (1991-1992) and a drought year (1988-1989). **Table I-1** and **Figure I-3** are organized to show the relative contributions of G-92 and Jupiter Farms to the total flow across Lainhart Dam, which is the primary source of freshwater flow to the Northwest Fork, and to compare this input with the inflows from the other major tributaries. Once again, it should be noted that MODFLOW is primarily a computer software code for evaluating groundwater flow conditions. The code utilized in this report does not incorporate a surface/groundwater module. Therefore, overland flow and associated surface water routing through canal networks is not directly simulated and the estimates of consumptive use withdrawals on overland flows should only be considered as gross estimates.

Table I-1. Water Budget Flows (cfs) for Average and Dry years for “1988-1995 Actual Pumpage”, “Permitted”, and “No Pumping” Model Runs (see text for explanation).

| **Sub-Basin** | **Ave. daily flow** | | **Basin** | **Ave. daily flow** | | **Watershed** | **Ave. daily flow** | |
|---|---|---|---|---|---|---|---|---|
| | **Dry✠** | **Ave.**** | | **Dry✠** | **Ave.**** | | **Dry✠** | **Ave.**** |
| “1988-1995 Actual Pumpage” **Model Run** | | | | | | | | |
| G-92* | 27 | 154 | Lainhart Dam* | 56 | 164 | Loxahatchee Estuary | 102 | 235 |
| Jupiter Farms* | 29 | 10 | | | | | | |
| | | | Hobe Grove Ditch | 6 | 11 | | | |
| | | | Kitching Creek | 4 | 12 | | | |
| | | | Cypress Creek | 36 | 48 | | | |
| **“Permitted” Model Run** | | | | | | | | |
| G-92* | 21 | 147 | Lainhart Dam* | 49 | 156 | Loxahatchee Estuary* | 95 | 227 |
| Jupiter Farms* | 28 | 9 | | | | | | |
| | | | Hobe Grove Ditch | 6 | 11 | | | |
| | | | Kitching Creek | 4 | 12 | | | |
| | | | Cypress Creek | 36 | 48 | | | |
| **“No Pumping” Model Run** | | | | | | | | |
| G-92* | 30 | 155 | Lainhart Dam* | 59 | 165 | Loxahatchee Estuary* | 105 | 236 |
| Jupiter Farms* | 29 | 10 | | | | | | |
| | | | Hobe Grove Ditch | 6 | 11 | | | |
| | | | Kitching Creek | 4 | 12 | | | |
| | | | Cypress Creek | 36 | 48 | | | |

✠Dry =Average Daily CFS from 1988-1989; **Average = Average Daily CFS from 1991-1992; *Calculated from Model

**Table I-1** considers the actual field data collected for the analysis of the “1988-1995 Actual Pumpage” condition. The flows delivered from G-92 and Jupiter Farms to the Lainhart Dam, were estimated from the model and adjusted to equal actual flows

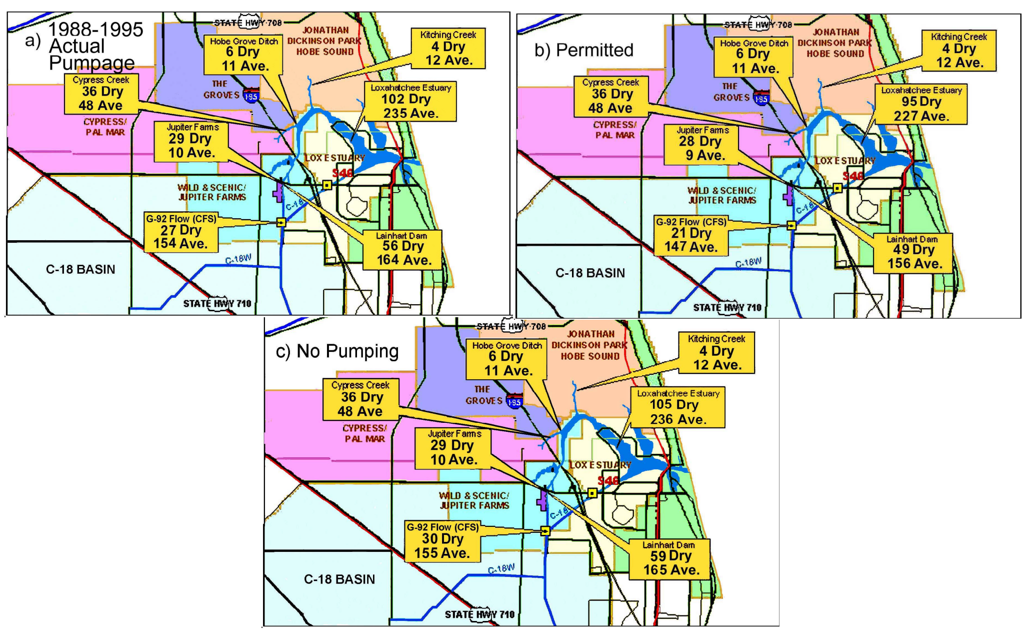


Figure 1-3. Flows to the Loxahatchee River from tributary basins and structures during dry and average rainfall conditions, based on the a) “1988-1995 Actual Pumpage,” b) “Permitted” and c) “No-Pumping” model runs.

across Lainhart Dam for the "1988-1995 Actual Pumpage" condition. The "Permitted" and "No Pumping" scenarios are simulated conditions and did not actually occur during those years. For those two runs, flows were estimated at Lainhart Dam based upon the net change in observed seepage compared to the actual, unmodified, seepage values as determined by the model and shown in **Figure I-4.**

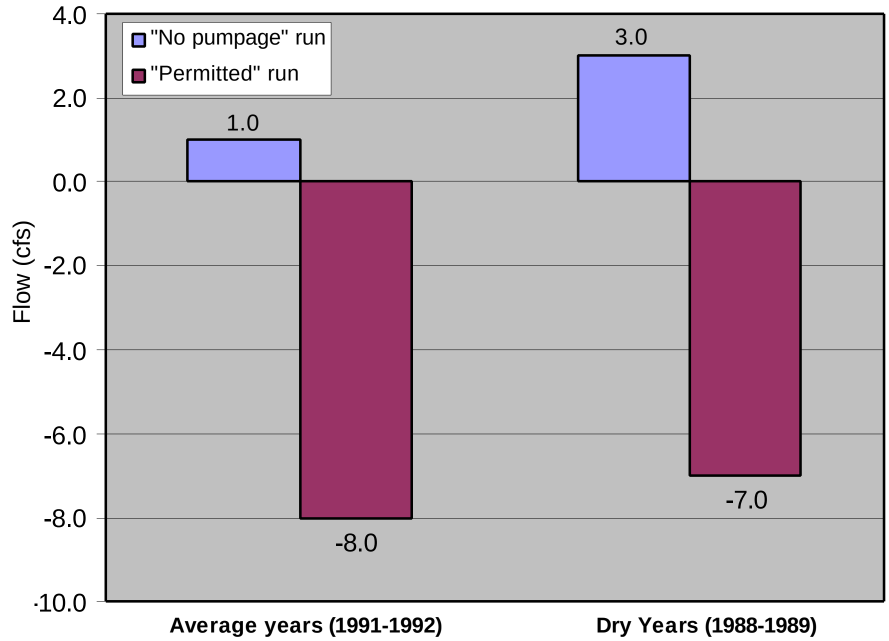


Figure 1-4. Net change in groundwater seepage from the C-18/Jupiter Farms Basin as compared to the "1988-1995 Actual Pumpage" run. Dry year (1988-89) estimates do not include the effects of mandatory water restrictions

Flows received from Cypress Creek, Hobe Groves Ditch and Kitching Creek were based on actual flow records. Figure I-3. Flows to the Loxahatchee River from Tributary Basins and Structures during Dry and Average Rainfall Conditions were based on the a) "1988-1995 Actual Pumpage," b) "Permitted," and c) "No-Pumping" model runs.

**Table I-1** shows that the projected average daily flow to the Loxahatchee Estuary during an average rainfall year under the "No Pumping" scenario is 236 cfs and during a drought year is 105 cfs. For the "Permitted" scenario, 227 cfs was provided to the estuary under average rainfall conditions and 95 cfs during drought conditions. This indicates that all permitted and exempt consumptive uses account for a potential net reduction of less than 10 cfs, under drought conditions, from the C-18/Jupiter Farms Basin to the Northwest Fork. Mandatory water restrictions under drought conditions were not simulated in the model scenario. Therefore the actual net reduction may be significantly less than 10 cfs. Under average rainfall conditions, the effect of pumping was estimated to be a 9 cfs reduction, which represents a 4 percent reduction in total freshwater river flow to the estuary.

A separate model run was made to estimate the effects of different classes of Consumptive Use Permits that have been issued in the area. Pumpages were classified as utility, irrigation, and domestic self supplied. The results suggest that of the total 9 cfs (under average rainfall conditions), public water supply wells may account for approximately 75 percent (6.8 cfs), whereas irrigation and residential self-supplied demands account for the remaining 25 percent (2.2 cfs) of total flow reduction. As many of the permitted withdrawals have not been realized, these estimates should be considered to be conservative.

It should be noted that the Town of Jupiter and the Village of Tequesta have begun or are in the process of utilizing the Floridan Aquifer to help meet existing and future demands. In addition, extensive use of reclaimed water has also been implemented by Loxahatchee River Environmental Control District and Seacoast Utilities for irrigation demands to help reduce stress on the aquifer.

## Potential Effects on Wetlands

As part of these analyses, District staff evaluated the effects of consumptive use withdrawals on local wetland areas, using a suite of indicator regions to estimate the degree of stress to these wetlands. The indicator regions, which were chosen to represent areas where effects were likely to occur, are listed in **Table I-2.**

**Table I-2. Indicator regions selected to represent water level conditions in the Loxahatchee River Watershed.**

| Indicator Region No. | Location |
|---|---|
| **44** | Just west of C-18-E Canal |
| **40** | Near the north end of the sloughs, west of C-18 canal |
| **35** | Near the south end of the sloughs, west of C-18 E Canal |
| **46** | East of the slough near the juncture of C-18 E and C-18 W |
| **950** | Just east of the C-18 W Canal |

**Figure I-5** shows the locations of model grid cells and indicator regions in the major wetland areas (West Palm Beach Water Catchment Area, Loxahatchee Slough and the Corbett Area) of the NPB Model domain. Stage duration curves were generated by the model for each of the indicator regions. These curves show the period of inundation for the particular indicator region, and can be used to assess wetland effects. **Figure I-6** shows the stage duration curves for indicator regions 44, 40, 35, 46, and 950. The stage duration curve have been normalized with respect to the land surface elevation.

Comparisons of stage duration curves for the "pumps off' vs. "permitted" scenarios show that consumptive uses may affect the indicator regions to the east of the Loxahatchee Slough (950 and 46) more than they affect the indicator regions to the west of the slough (35, 40, and 44). However, drawdowns appear to be less than 1 foot in these indicator regions suggesting that these regions have met the consumptive use resource protection criteria and have not been affected significantly by groundwater withdrawals (**Figure I-6**).

In summary, modeling studies of the northern Palm Beach County portion of the Loxahatchee River watershed indicate that consumptive uses within the Loxahatchee Basin have observable effects on flow to the Northwest Fork during drought events. The effects of these withdrawals are probably insignificant during wet and average years, but may result in minor reductions of flows across Lainhart Dam during dry periods.

During dry periods, the overall effect of permitted consumptive uses and exempt withdrawals on total flow of freshwater to the Northwest Fork and the estuary represents a decrease of less than 10 cfs, or less than a 10 percent reduction in total flow of freshwater to the estuary. During normal rainfall periods, the reduction in flow to the estuary may be on the order of 4 percent.

These estimates are considered to be conservative, because permitted withdrawals have not yet been realized, some permitted withdrawals have shifted to alternative sources, and the flow estimation capabilities of the model are limited.

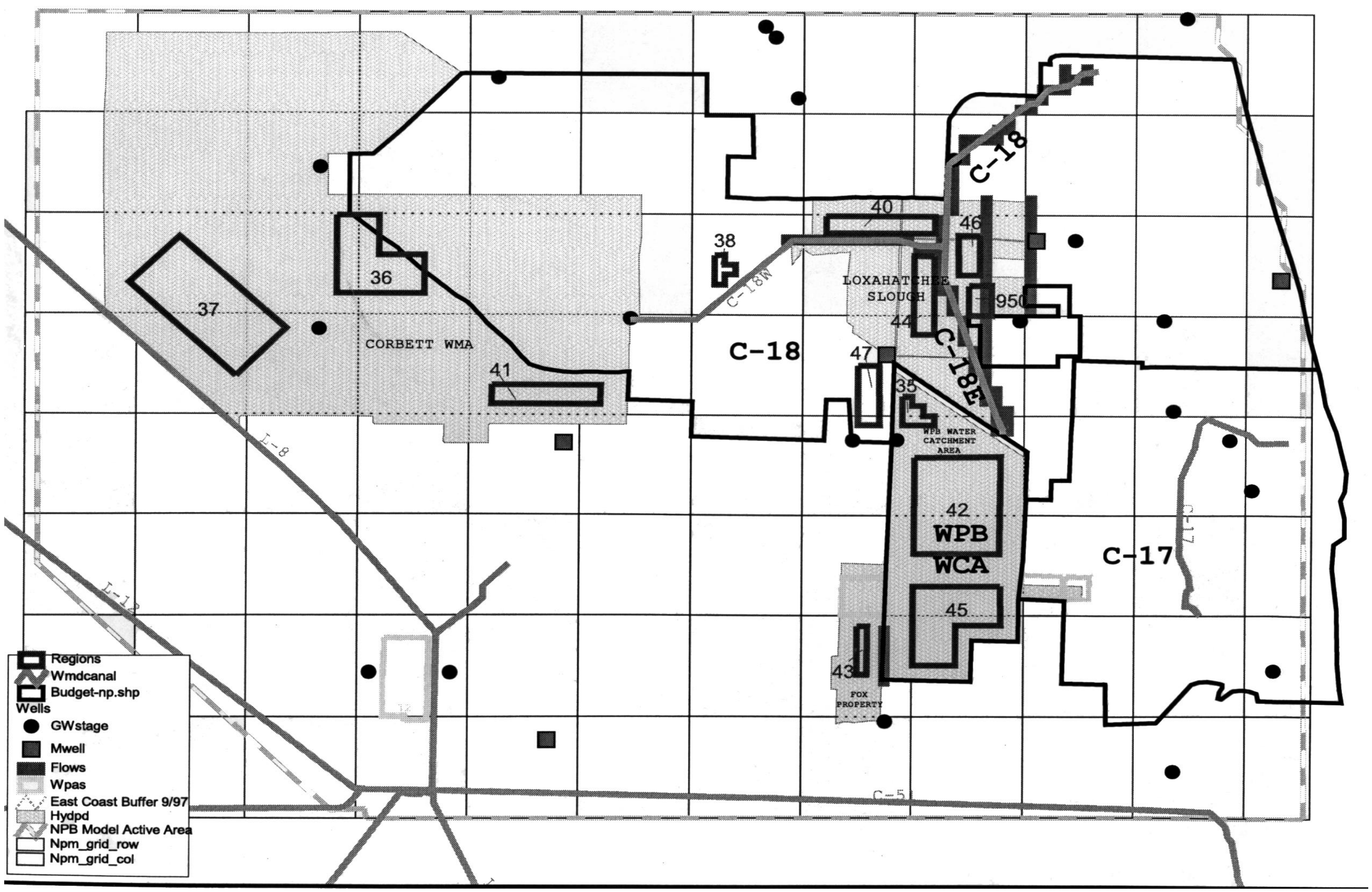


Figure I-5. Locations of Indicator Regions in the Northern Palm Beach Groundwater Model

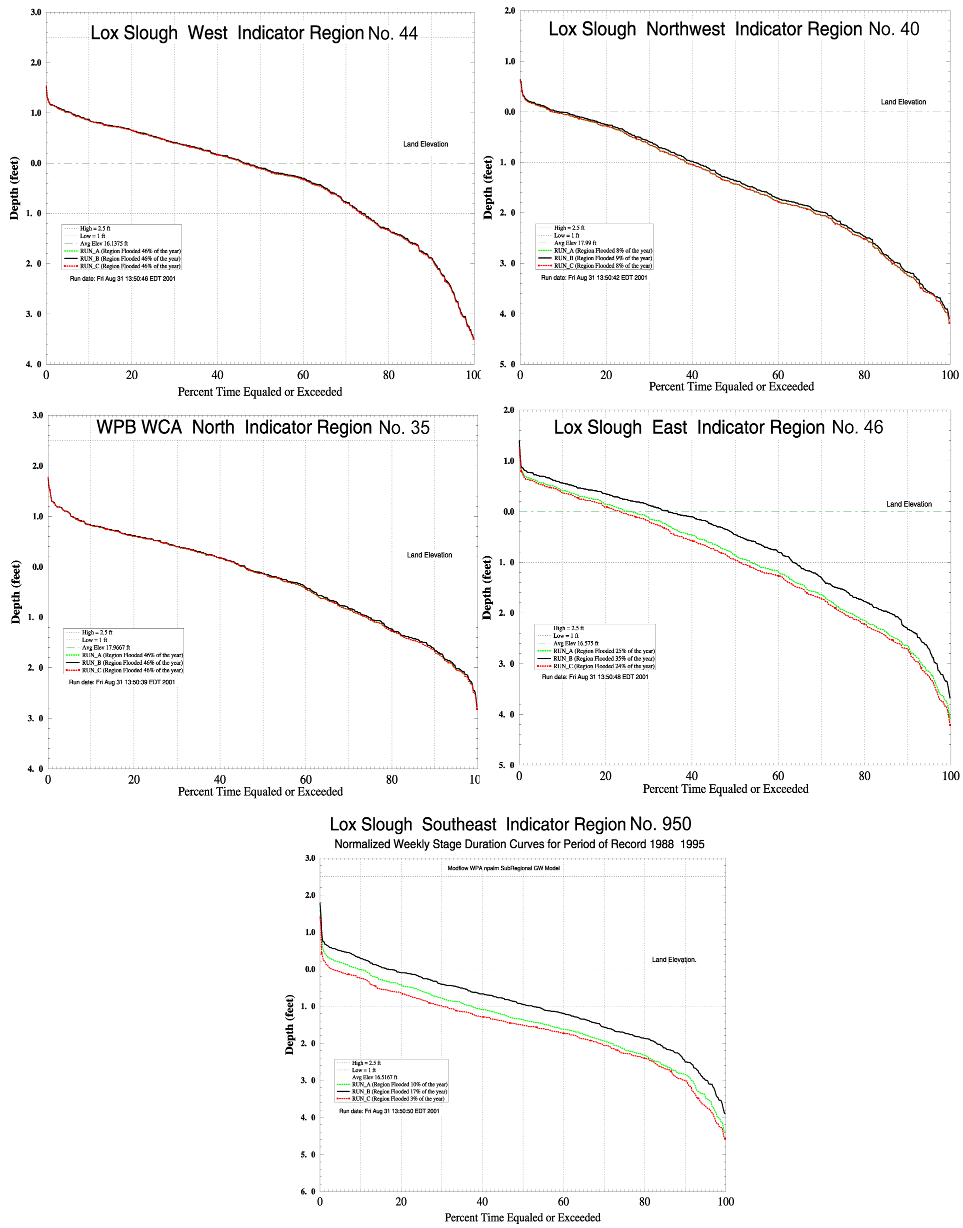


Figure I-6. Stage Duration Curves for Loxahatchee Slough Indicator Regions for the permitted (red), “1988-1995 Actual Pumpage” (green), and “pumps off” (black) model runs.